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A review about the mechanisms associated with active deformation, regional uplift and subsidence in southern South America

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ABSTRACT

A broad range of processes acted simultaneously during the Quaternary producing relief in the Andes and adjacent foreland, from the Chilean coast, where the Pacific Ocean floor is being subducted beneath South American, to the Brazilian and the Argentinean Atlantic platform area. This picture shows to be complex and responds to a variety of processes. The Geoid exemplifies this spectrum of uplift mechanisms, since it reflects an important change at 35°S along the Andes and the foreland that could be indicating the presence of dynamic forces modeling the topography with varying intensity through the subduction margin. On the other hand, mountains uplifted in the Atlantic margin, along a vast sector of the Brazilian Atlantic coast and inland regions seem to be created at the area where the passive margin has been hyper-extended and consequently mechanically debilitated and the forearc region shifts eastwardly at a similar rate than the westward advancing continent. Therefore the forearc at the Arica latitudes can be considered as relatively stationary and dynamically sustained by a perpendicular-to-the-margin asthenospheric flow that inhibits trench roll back, determining a highly active orogenic setting at the eastern Andes in the Subandean region. To the south, the Pampean flat subduction zone creates particular conditions for deformation and rapid propagation of the orogenic front producing a high-amplitude orogen. In the southern Central and Patagonian Andes, mountain (orogenic) building processes are attenuated, becoming dominant other mechanisms of exhumation such as the i) impact of mantle plumes originated in the 660 km mantle transition, ii) the ice-masse retreat from the Andes after the Pleistocene producing an isostatic rebound, iii) the dynamic topography associated with the opening of an asthenospheric window during the subduction of the Chile ridge and slab tearing processes, iv) the subduction of oceanic swells linked to transform zones and v) the accretion of oceanic materials beneath the forearc region. Additionally and after last geodetic studies, vi) exhumation due to co- and post-seismic lithospheric stretching associated with large earthquakes along the subduction zone, also shows to be a factor associated with regional uplift that needs to be further considered as an additional mechanism from the Chilean coast to the western retroarc area. Finally, this revision constitutes a general picture about the different mechanisms of uplift and active deformation along the Southern Andes, in which orogenic processes become dominant north of 35°S, while south of these latitudes dynamic forces seem to predominate all over the Patagonian platform.

1. Introduction

Active uplift in the Andes has been generally associated with contraction imposed by the convergence between the oceanic Nazca and Antarctic subducted plates and the South American plate (Ramos et al., 2004; Costa et al., 2006; Oncken et al., 2006; Schellart

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et al., 2011). However, in the last years multiple mechanisms have been recognized along the Andes that produce, together with orogenic forces, regional to local uplift and eventually exhumation of the upper crust. These additional mechanisms involve isostatic readjustments due to crustal stretching interrupting Andean constructional stages and delamination, to co-seismic extension, lower crustal flow, accretion of underplated materials associated with tectonic erosion, and even deep mantle dynamics. Additionally, segments where exhumation seems to be governed by thrusting are not clearly delimited and their associated mechanisms are not totally understood.

In general terms a narrow band of thrusts has been described bordering the eastern Altiplano and Pampean regions from southern Perú and Bolivia to northern and central Argentina between 10° and 33°S (Fig. 1). This segment coincides with a broad and high mountain chain associated with important amounts of intracrustal earthquakes that denote active mountain building processes (see Costa et al., 2006 for a review). South of 33°S, crustal seismicity on the eastern Andes diminishes sensibly, becoming mountain morphology narrower and lower. Even though orogenic mechanisms are described for this southern sector of the Andes at least discontinuously, other factors have been linked to regional and local uplift in the last years, in particular for the Patagonian region.

This review outlines the main processes that are associated with uplift and exhumation of vast sectors of the Southern Andes and their foreland area. These processes, mainly recognized in the last years since technological innovations, have allowed i) recognizing centimeter to millimeter fluctuations of the landscape, ii) illuminating the thermal structure of the lower crust and upper mantle, and iii) analyzing variations in the gravity field through time, from the Altiplano region to Patagonia passing through the foreland area and even the passive margin where no subduction of oceanic lithosphere exists.

2. Central and Patagonian Andes tectonic setting

The Andes are formed over a subduction system consisting of three oceanic plates, Cocos, Nazca and Antarctica, subducting beneath the South American plate. This configuration shows a noticeable symmetry with an orogenic plateau at its mid sector flanked by two flat subduction systems, the Peruvian in the north and the Pampean in the south (Fig. 1) (Gephart, 1994). Topography is higher at the mid sector and diminishes steadily towards both edges of the subduction system, where narrow mountain systems are connected to transform-plate boundaries between the South America, Caribbean and Scotia plates respectively (Fig. 1). An active arc is produced at the sites where the subduction configuration is steeper than 20–30° and oceanic lithosphere subducts with ages older than 5 My, and is discontinued through four magmatic gaps along the Andes.

Even though this system shows a striking symmetry, from north to south the Nazca and Antarctic plates sink beneath the western border of South America at different rates. While Nazca plate penetrates beneath the continent with varying-relatively high rates between 6 and 7 cm/yr, the Antarctic plate sinks at less than 2 cm/yr (Kendrick et al., 1999). This change has been attributed to the ridge-trench collision and the migration of the triple junction point from south to north in the last 14 My between Nazca, Antarctica and South American plates. This provoked the opening of an asthenospheric window beneath Patagonia and a mechanical disconnection between Antarctica and Nazca plates at depth, consequently producing a drastic drop in slab pull forces (Cande and Leslie, 1986; Ramos and Kay, 1992; Maksymowicz et al., 2012).

3. Regional uplift in the Central Andes and Atlantic passive margin

An anomalously high topography is developed north and south of the Arica bend region around the Altiplano (Fig. 1). This topography is correlated with an unusually high crustal thickening in the order of 70–75 km, estimated by geophysical methods, that can't be fully explained by shortening in the retroarc zone (Baby et al., 1997). However, these shortening estimates can be considered as conservative according to other studies (see McQuarrie et al., 2005). This lack in correlation between shortening estimates and crustal thickening according to some authors has been explained by lower crustal underplated materials beneath the eastern Altiplano, eroded tectonically from the forearc and/or lower crustal flow in regions of thermally weakened middle and lower crust, respectively, accounting for the high orogenic volumes (Baby et al., 1997; Hindle et al., 2005). More recent proposals analyze this setting in a regional view considering that both flat slabs that flank the Altiplano region, which are tomographically rigid and cold, would freeze the orogen-parallel crustal flow inhibiting redistribution of material, resulting in a broad plateau above the central slab (Ouimet and Cook, 2010).

Other proposals imply that the Altiplano region is elevated by delamination of the lower lithosphere (Kay and Kay, 1993; McQuarrie et al., 2005; Asch et al., 2006; Calixto et al., 2013) producing a high topography partially linked to isostatic readjustments (Isacks, 1988; Sobolev and Babeyko, 2005; Dávila et al., 2012). This feature is eastwardly flanked by the Eastern Cordillera and Subandean system, with a deep decollement in the Paleozoic basement, frontally inserted in Paleozoic sections that accommodated contraction since the last 10 Ma up to the present (Echavarría et al., 2003; Ramos et al., 2004; Oncken et al., 2006; Brooks et al., 2011). At the Atlantic Brazilian coastal zone another topographic anomaly is recognized in a passive margin (Fig. 1). This has been associated with active mountain uplifts restricted to the Atlantic coastal area associated with crustal seismicity and neotectonics (Bezerra et al., 2006; Riccomini and Assumpção, 1999; Rossetti et al., 2012). These uplifts are roughly coincident with the area where the Chilean forearc is relatively stationary respect to the Brazilian Atlantic spreading center (Schellart et al., 2007, 2011). While the Brazilian craton displaces north-westwardly some 20 mm/year, the northern Chilean coast moves between 22.9 and 23.5 mm/year eastwardly implying that part of these displacements is absorbed as permanent deformation in the area interposed between, where the World Stress Map provides robust evidence for ongoing E–W compression (Kendrick et al., 1999; Heidbach et al., 2008).

Even though the main part of this contraction is indeed absorbed at the Subandean region (Brooks et al., 2011), a fraction is accommodated at the Brazilian coastal zone (Fig. 1). This situation seems to be a longstanding phenomenon since thermochronological data along the Brazilian coast show Cretaceous, Eocene and Miocene exhumations that represent exactly the known Andean growth stages at these latitudes (Cogné et al., 2012). To the south, the Chilean forearc escapes westwardly away the Argentinean craton, accommodating rates less than 1 mm/year of elastic and permanent deformation in the Andes. In this context, the interposed area does not experience high amounts of contraction such as to the north (Fig. 1), since the trench moves to the Pacific Ocean at similar rates than the north-westwardly advancing continent (Schellart et al., 2007). Active mountain uplift and crustal seismicity at the southern Atlantic coast can be also partially understood by the development of a hyper-extended margin in the Brazilian continental platform (Fig. 1) (see Brune et al., 2014). Hyper-extended margins at these latitudes formed next to the Euler pole